

WHAT IS CLAIMED IS:

1 1. An antenna system, comprising:
2 an antenna array, comprising:
3 a plurality of antenna elements; and
4 an antenna beamforming system;
5 a calibration system adapted to calibrate the antenna array in either a transmit
6 mode or a receive mode, the calibration system comprising:
7 a plurality of calibration probes interleaved with the plurality of antenna
8 elements, the calibration probes adapted to be transmit calibration probes or receive
9 calibration probes;
10 a calibration processing system adapted to calibrate the antenna array utilizing
11 the interleaved calibration probes.

1 2. The antenna system as recited in claim 1, wherein the calibration
2 processing system calibrates the antenna array by performing control circuit encoding (CCE)
3 calibration on the array.

1 3. The antenna system as recited in claim 1, wherein the antenna
2 beamforming system is adapted to generate a plurality of beams, and wherein the
3 beamforming system comprises an RF signal path to each element of the antenna array for
4 each of the plurality of beams.

1 4. The antenna system as recited in claim 3, wherein each signal path
2 comprises a phase shifter, and wherein the calibration system calibrates the phase shifters.

1 5. The antenna system as recited in claim 3, wherein each signal path
2 comprises an attenuator, and wherein the calibration system calibrates the attenuators.

1 6. An antenna system, comprising:
2 an antenna array, comprising:
3 a plurality of antenna elements; and
4 an antenna beamforming system;
5 a calibration system adapted to calibrate the antenna array in either a transmit
6 mode or a receive mode, the calibration system comprising:

7 a plurality of calibration probes interleaved with the plurality of
8 antenna elements, the calibration probes adapted to be transmit calibration probes or
9 receive calibration probes;
10 a calibration tone signal generator adapted to generate a calibration
11 tone, wherein the calibration tone is input to the antenna array when the antenna array
12 is in transmit mode, and wherein the calibration tone is input to the plurality of
13 calibration probes when the antenna array is in the receive mode;
14 an encoding signal generator adapted to generate sets of encoding
15 signal values, and wherein the sets of encoding signal values are input to the antenna
16 array, and the antenna array encodes the calibration tone signal traversing the antenna
17 array with the sets of encoding signal values, generating encoded calibration signals;
18 and
19 a signal decoding and processing system adapted to decode and
20 process the encoded calibration signals to produce calibration data for the antenna
21 array.

1 7. The antenna system as recited in claim 6, wherein each set of encoding
2 signal values are orthogonal to other sets of encoding signal values.

1 8. The antenna system as recited in claim 6, wherein the antenna
2 beamforming system is adapted to generate a plurality of beams, and wherein the
3 beamforming system comprises an RF signal path to each element of the antenna array for
4 each of the plurality of beams.

1 9. The antenna system as recited in claim 8, wherein each signal path
2 comprises a phase shifter, and wherein the signal decoding and processing system produces
3 calibration data representative of the phase corrections for the phase shifters.

1 10. The antenna system as recited in claim 8, wherein each signal path
2 comprises an attenuator, and wherein the signal decoding and processing system produces
3 calibration data representative of amplitude corrections for the attenuators.

1 11. The antenna system as recited in claim 6, wherein the calibration
2 system further comprises a switch for switching between the plurality of calibration probes.

1 12. The antenna system as recited in claim 6, wherein the antenna array is
2 operating in transmit mode, and wherein the antenna system is adapted such that:
3 the antenna array receives the calibration tone signal from the calibration tone
4 signal generator, encodes the calibration tone signal with the sets of encoding signal values,
5 generating the encoded calibration signals, and transmits the encoded calibration signals;
6 one or more of the calibration probes receive the encoded calibration signals
7 and transmit the signals to the signal decoding and processing system; and
8 the signal decoding and processing system produces the calibration data for
9 the antenna array.

1 13. The antenna system as recited in claim 12, wherein the antenna
2 beamforming system is adapted to generate a plurality of beams, and wherein the
3 beamforming system comprises an RF signal path to each element of the antenna array for
4 each of the plurality of beams, and wherein the calibration system is adapted to calibrate the
5 signal paths to each of the antenna elements associate with a particular beam at one time,
6 such that each of the encoded calibration signals are associated with each of the signal paths
7 for the particular beam being calibrated.

1 14. The antenna system as recited in claim 13, wherein each of the antenna
2 elements of the antenna array are radiatively coupled with a plurality of calibration probes, so
3 that each signal path will have a plurality of encoded calibration signals associated with it.

1 15. The antenna system as recited in claim 14, wherein the calibration
2 system further comprises a switch for switching between the plurality of calibration probes,
3 and wherein the signal decoding and processing system decodes and processes encoded
4 calibration signals from the calibration probe to which the switch is connected, generating
5 calibration data for each of the signal paths for the particular calibration probe to which the
6 switch is connected.

1 16. The antenna system as recited in claim 15, wherein the signal decoding
2 and processing system generates calibration data for each of the calibration probes separately,
3 and wherein the calibration data for each of the signal paths generated from each of the
4 calibration probes are combined to generate one set of calibration data for each of the signal
5 paths.

1 17. The antenna system as recited in claim 16, wherein the calibration data
2 for each of the signal paths generated from each of the probes are adjusted based-on the
3 location of the associated probe within the antenna array before the calibration data is
4 combined.

1 18. The antenna system as recited in claim 16, wherein the calibration data
2 are combined by averaging the calibration data from each of the calibration probes.

1 19. The antenna system as recited in claim 18, wherein prior to averaging
2 the calibration data from each of the calibration probes, the calibration data from each
3 calibration probe is weighted based on the signal-to-noise ratio for signals from the
4 calibration probes.

1 20. The antenna system as recited in claim 6, wherein the antenna array is
2 operating in receive mode, and wherein the antenna system is adapted such that:
3 the plurality of calibration probes receive the calibration tone signal from the
4 calibration tone signal generator and transmit the calibration tone to the antenna array;
5 the antenna array receives the calibration tone signal from the plurality of
6 calibration probes, encodes the calibration tone signal with the sets of encoding signal values,
7 generating the encoded calibration signals, and transmits the encoded calibration signals to
8 the signal decoding and processing system; and
9 the signal decoding and processing system produces the calibration data for
10 the antenna array.

1 21. The antenna system as recited in claim 20, wherein the antenna
2 beamforming system is adapted to generate a plurality of beams, and wherein the
3 beamforming system comprises an RF signal path to each element of the antenna array for
4 each of the plurality of beams, and wherein the calibration system is adapted to calibrate the
5 signal paths to each of the antenna elements associate with a particular beam at one time,
6 such that each of the encoded calibration signals are associated with each of the signal paths
7 for the particular beam being calibrated.

1 22. The antenna system as recited in claim 21, wherein the calibration
2 system further comprises a switch for switching between the plurality of calibration probes,
3 and wherein the antenna system is adapted such that:

4 the antenna array receives and encodes a calibration tone signal transmitted
5 from the calibration probe to which the switch is attached, generating probe encoded
6 calibration signals for each of the signal paths; and
7 the signal decoding and processing system decodes and processes the probe
8 encoded calibration signals, generating a probe calibration data for each of the signal paths
9 for the particular calibration probe to which the switch is connected.

1 23. The antenna system as recited in claim 22, the signal decoding and
2 processing system generates probe calibration data for each of the calibration probes
3 separately, and wherein the probe calibration data for each of the signal paths generated from
4 each of the probes are combined to generate one set of calibration data for each of the signal
5 paths.

1 24. The antenna system as recited in claim 23, wherein the probe
2 calibration data for each of the signal paths generated from each of the probes is adjusted
3 based-on the location of the associated probe within the antenna array before the calibration
4 data are combined.

1 25. The antenna system as recited in claim 23, wherein the calibration data
2 are combined by averaging the calibration data from each of the calibration probes.

1 26. The antenna system as recited in claim 25, wherein prior to averaging
2 the calibration data from each of the calibration probes, the calibration data from each
3 calibration probe is weighted based on the signal-to-noise ratio for signals from the
4 calibration probes.

1 27. The antenna system as recited in claim 6, wherein the antenna elements
2 of the antenna array comprise antenna elements selected from the group consisting of helical
3 antenna elements, micro-strip patch antenna elements, horn antenna elements or dipole
4 antenna elements.

1 28. The antenna system as recited in claim 6, wherein the antenna array
2 comprises a plurality of antenna arrays, and wherein the plurality of calibration probes are
3 interleaved with the plurality of antenna arrays.

1 29. The antenna system as recited in claim 28, wherein at least some of the
2 plurality of antenna arrays are interleaved with each other.

1 30. The antenna system as recited in claim 6, wherein the antenna system
2 comprises a redundant calibration system.

1 31. The antenna system as recited in claim 30, wherein the redundant
2 calibration system is the same as the calibration system.

1 32. The antenna system as recited in claim 30, wherein the redundant
2 calibration system is the same as the calibration system except that the redundant calibration
3 system and the calibration system share the same calibration probes.

1 33. A spacecraft including an antenna system, comprising:
2 an antenna array, comprising:
3 a plurality of antenna elements; and
4 an antenna beamforming system;
5 a calibration system adapted to calibrate the antenna array in either a transmit
6 mode or a receive mode, the calibration system comprising:
7 a plurality of calibration probes interleaved with the plurality of
8 antenna elements, the calibration probes adapted to be transmit calibration probes or
9 receive calibration probes;
10 a calibration tone signal generator adapted to generate a calibration
11 tone, wherein the calibration tone is input to the antenna array when then antenna
12 array is in transmit mode, and wherein the calibration tone is input to the plurality of
13 calibration probes when the antenna array is in the receive mode;
14 an encoding signal generator adapted to generate sets of encoding
15 signal values, and wherein the sets of encoding signal values are input to the antenna
16 array, and the antenna array encodes the calibration tone signal traversing the antenna
17 array with the sets of encoding signal values, generating encoded calibration signals;
18 and
19 a signal decoding and processing system adapted to decode and
20 process the encoded calibration signals to produce calibration data for the antenna
21 array.

1 34. The spacecraft as recited in claim 33, wherein each set of encoding
2 signal values are orthogonal to other sets of encoding signal values.

1 35. The spacecraft as recited in claim 33, wherein the antenna
2 beamforming system is adapted to generate a plurality of beams, and wherein the
3 beamforming system comprises an RF signal path to each element of the antenna array for
4 each of the plurality of beams.

1 36. The spacecraft as recited in claim 35, wherein each signal path
2 comprises a phase shifter, and wherein the signal decoding and processing system produces
3 calibration data representative of the phase corrections for the phase shifters.

1 37. The spacecraft as recited in claim 35, wherein each signal path
2 comprises an attenuator, and wherein the signal decoding and processing system produces
3 calibration data representative of amplitude corrections for the attenuators.

1 38. The spacecraft as recited in claim 33, wherein the calibration system
2 further comprises a switch for switching between the plurality of calibration probes.

1 39. The spacecraft as recited in claim 33, wherein the antenna array is
2 operating in transmit mode, and wherein the antenna system is adapted such that:
3 the antenna array receives the calibration tone signal from the calibration tone
4 signal generator, encodes the calibration tone signal with the sets of encoding signal values,
5 generating the encoded calibration signals, and transmits the encoded calibration signals;
6 one or more of the calibration probes receive the encoded calibration signals
7 and transmit the signals to the signal decoding and processing system; and
8 the signal decoding and processing system produces the calibration data for
9 the antenna array.

1 40. The spacecraft as recited in claim 39, wherein the antenna
2 beamforming system is adapted to generate a plurality of beams, and wherein the
3 beamforming system comprises an RF signal path to each element of the antenna array for
4 each of the plurality of beams, and wherein the calibration system is adapted to calibrate the
5 signal paths to each of the antenna elements associate with a particular beam at one time,

6 such that each of the encoded calibration signals are associated with each of the signal paths
7 for the particular beam being calibrated.

1 41. The spacecraft as recited in claim 40, wherein each of the antenna
2 elements of the antenna array are radiatively coupled with a plurality of calibration probes, so
3 that each signal path will have a plurality of encoded calibration signals associated with it.

1 42. The spacecraft as recited in claim 41, wherein the calibration system
2 further comprises a switch for switching between the plurality of calibration probes, and
3 wherein the signal decoding and processing system decodes and processes encoded
4 calibration signals from the calibration probe to which the switch is connected, generating
5 calibration data for each of the signal paths for the particular calibration probe to which the
6 switch is connected.

1 43. The spacecraft as recited in claim 42, wherein the signal decoding and
2 processing system generates calibration data for each of the calibration probes separately, and
3 wherein the calibration data for each of the signal paths generated from each of the
4 calibration probes are combined to generate one set of calibration data for each of the signal
5 paths.

1 44. The spacecraft as recited in claim 43, wherein the calibration data for
2 each of the signal paths generated from each of the probes are adjusted based-on the location
3 of the associated probe within the antenna array before the calibration data is combined.

1 45. The spacecraft as recited in claim 43, wherein the calibration data are
2 combined by averaging the calibration data from each of the calibration probes.

1 46. The antenna system as recited in claim 45, wherein prior to averaging
2 the calibration data from each of the calibration probes, the calibration data from each
3 calibration probe is weighted based on the signal-to-noise ratio for signals from the
4 calibration probes.

1 47. The spacecraft as recited in claim 33, wherein the antenna array is
2 operating in receive mode, and wherein the antenna system is adapted such that:
3 the plurality of calibration probes receive the calibration tone signal from the
4 calibration tone signal generator and transmit the calibration tone to the antenna array;

5 the antenna array receives the calibration tone signal from the plurality of
6 calibration probes, encodes the calibration tone signal with the sets of encoding signal values,
7 generating the encoded calibration signals, and transmits the encoded calibration signals the
8 signal decoding and processing system; and

9 the signal decoding and processing system produces the calibration data for
10 the antenna array.

1 48. The spacecraft as recited in claim 47, wherein the antenna
2 beamforming system is adapted to generate a plurality of beams, and wherein the
3 beamforming system comprises an RF signal path to each element of the antenna array for
4 each of the plurality of beams, and wherein the calibration system is adapted to calibrate the
5 signal paths to each of the antenna elements associate with a particular beam at one time,
6 such that each of the encoded calibration signals are associated with each of the signal paths
7 for the particular beam being calibrated.

1 49. The spacecraft as recited in claim 48, wherein the calibration system
2 further comprises a switch for switching between the plurality of calibration probes, and
3 wherein the antenna system is adapted such that:

4 the antenna array receives and encodes a calibration tone signal transmitted
5 from the calibration probe to which the switch is attached generating, probe encoded
6 calibration signals for each of the signal paths; and

7 the signal decoding and processing system decodes and processes the probe
8 encoded calibration signals, generating a probe calibration data for each of the signal paths
9 for the particular calibration probe to which the switch is connected.

1 50. The spacecraft as recited in claim 49, the signal decoding and
2 processing system generates probe calibration data for each of the calibration probes
3 separately, and wherein the probe calibration data for each of the signal paths generated from
4 each of the probes are combined to generate one set of calibration data for each of the signal
5 paths.

1 51. The spacecraft as recited in claim 50, wherein the probe calibration
2 data for each of the signal paths generated from each of the probes is adjusted based-on the
3 location of the associated probe within the antenna array before the calibration data are
4 combined.

1 52. The spacecraft as recited in claim 50, wherein the calibration data are
2 combined by averaging the calibration data from each of the calibration probes.

1 53. The antenna system as recited in claim 52, wherein prior to averaging
2 the calibration data from each of the calibration probes, the calibration data from each
3 calibration probe is weighted based on the signal-to-noise ratio for signals from the
4 calibration probes.

1 54. The spacecraft as recited in claim 33, wherein the antenna elements of
2 the antenna array comprise antenna elements selected from the group consisting of helical
3 antenna elements, micro-strip patch antenna elements, horn antenna elements or dipole
4 antenna elements.

1 55. The spacecraft as recited in claim 33, wherein the antenna array
2 comprises a plurality of antenna arrays, and wherein the plurality of calibration probes are
3 interleaved with the plurality of antenna arrays.

1 56. The spacecraft as recited in claim 55, wherein at least some of the
2 plurality of antenna arrays are interleaved with each other.

1 57. The spacecraft as recited in claim 33, wherein the antenna system
2 comprises a redundant calibration system.

1 58. The spacecraft as recited in claim 57, wherein the redundant
2 calibration system is the same as the calibration system.

1 59. The spacecraft as recited in claim 57, wherein the redundant calibration
2 system is the same as the calibration system except that the redundant calibration system and
3 the calibration system share the same calibration probes.